Daily cumulative hip moment is associated with radiographic progression of secondary hip osteoarthritis

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Running title: Daily cumulative hip moment and hip OA progression

ABSTRACT

Objective:

To investigate whether higher daily cumulative hip moment at baseline is associated with subsequent radiographic progression of hip osteoarthritis (OA) over 12 months.

Design:

Fifty patients with secondary hip OA, excluding patients with end-stage hip OA, participated in this prospective cohort study. Joint space width (JSW) of the hip was measured at baseline and 12 months later. With radiographic progression of hip OA (> 0.5 mm/year in JSW) as dependent variable (yes/no), univariable and multivariable logistic regression analyses were performed to assess the association between load-related parameters during gait (i.e., peak hip moment, hip moment impulse, and daily cumulative hip moment [product of hip moment impulse and mean steps/day]) and hip OA progression with and without adjustment for age, body weight, and minimum JSW.

Results:

Of the 50 patients (47.4 ± 10.7 years old), 21 (42.0%) were classified into the progression group. The higher daily cumulative hip moment in the frontal plane at baseline was statistically significantly associated with radiographic progression of hip OA (adjusted OR [95% CI], 1.34 [1.06–1.70]; P = 0.013). The higher daily cumulative hip moment in the sagittal plane was also approaching significance in its association with hip OA progression (adjusted OR, 1.80 [0.99–3.26]; P = 0.052).

Conclusions:

In the female patients with secondary hip OA, higher daily cumulative hip moment, particularly in the frontal plane, was a predictor of radiographic progression of hip OA over 12 months. Reduction in daily cumulative hip moment by modification in gait and physical activity may potentially slow hip OA progression.

Keywords: Hip osteoarthritis, Gait, Biomechanics, cumulative joint moment

INTRODUCTION

Although progression of hip osteoarthritis (OA) seems to be multifactorial, genetic mutation[1], higher age[2], female, narrower joint space width (JSW) and higher Kellgren and Lawrence score at baseline[2,3], abnormal hip morphology such as hip dysplasia[1,2,4,5], atrophic bone response[2,6], and hip pain[3] are known potential risk factors for progression of hip OA. Especially for secondary hip OA, which is more prevalent than primary OA[7], abnormal hip morphology and malalignment between acetabular and proximal femoral head play an important role in radiographic progression[4,8].

In knee OA, a mechanical factor (i.e., excessive knee adduction moment and moment impulse during gait) has been identified as an important contributor to OA progression[9–13]. However, gait biomechanics associated with progression of hip OA remain unknown. Extended exposure to heavy physical work such as heavy lifting and standing can increase the risk for hip OA[14], although it is not known whether excessive load during gait is related to progression of hip OA. A recent longitudinal study reported that patients with hip OA who later underwent total hip arthroplasty (THA) had less hip extension moment and hip extension angle during gait at baseline compared to those without surgery[15]. Although that study did not necessarily examine the causal relationship between gait and radiographic progression since the decision of operation depends on multiple factors, it highlights the need for investigation of the association between gait biomechanics and progression of hip OA. However, the mechanical risk factor during gait for hip OA progression has not been identified.

The external joint moment during gait can be used to estimate mechanical load since joint load cannot be directly measured *in vivo* noninvasively. Hip contact force during gait can be predicted from absolute hip joint moment in the three planes during the stance phase of gait[16,17]. Peak joint moment and joint moment impulse have been used as indicators of joint load[11,13]. Peak joint moment represents instantaneous load at a specific point during stance phase, and moment impulse measures the total amount of load during stance phase by incorporating both load magnitude and duration. Furthermore, total exposure to joint load during daily activities has been measured as daily cumulative joint moment calculated as the product of the moment impulse during the stance phase and the mean number of steps/day[18]. Daily cumulative moment may be particularly important, as it was nearly doubled in the patients with knee OA compared with the healthy individuals[19], and daily cumulative hip moment was associated with JSW in patients with hip OA in cross-sectional studies[20].

The purpose of this study was to evaluate the association between mechanical load during gait at baseline and subsequent radiographic progression of hip OA over 12 months. Given that cartilage degeneration depends on load magnitude and duration[21,22], it is possible that mechanical load during gait, especially daily cumulative hip moment rather than the peak moment and moment impulse, could critically influence degeneration of hip joint. We hypothesized that daily cumulative hip moment at baseline is associated with radiographic progression of hip OA.

PATIENTS AND METHODS

Patients

In this prospective cohort study, non-surgical outpatients were selected in the Department of Orthopaedic Surgery at Kyoto University Hospital. Patients with secondary hip OA aged 20 years and older were recruited from April 2013 to March 2015. A total of 53 patients were eligible for inclusion in our study, and were measured at baseline. Three patients were excluded from analysis because of missing measurements 12 months later.

The inclusion criteria were as follows: 1) a diagnosis of preosteoarthritis (acetabular dysplasia with no other abnormal radiographic findings) or early (slight joint space narrowing and abnormal subchondral sclerosis) or advanced-stage (marked joint space narrowing with or without cysts or sclerosis) hip OA, and 2) ability to walk without any assistive device in daily life. The exclusion criteria were as follows: 1) patients with a baseline JSW of < 0.5 mm, as more than 0.5 mm/year in

JSW was defined as progression of hip OA; 2) a history of previous hip surgeries (e.g., osteotomy, arthroplasty); and 3) neurologic, vascular, or other conditions that affect gait or activity of daily living.

Although the candidates for our study included both males and females, our sample was biased in gender (percentage of males: 7.1%), similar to previous reports on secondary hip OA (percentage of males: 7.6–9.2%)[8,23,24]. Therefore, only female patients were included in this study. Many of the patients had bilateral hip OA, and the side on which the radiographic OA change was more severe was used for analysis. All participants provided informed consent, and the protocol was approved by the Ethics Committee of the Kyoto University Graduate School and Faculty of Medicine (protocol identification number: E1683).

Radiographic assessment

A digital supine anteroposterior pelvic radiograph was obtained in a standardized manner by the same skilled radiology technicians at baseline and approximately 12 months later. The influence of position (supine versus standing) on the radiographic parameters of hip joint is discrepant[25–27]. However, radiographic parameters regarding hip dysplasia and joint space width differ little between supine and standing anteroposterior radiographs[25,27]. Therefore, to improve image quality, we used radiograph in the supine position. Radiography at baseline was performed within 30 days prior to gait analysis. To avoid unnecessary radiation exposure, we used radiographs taken for general practice. From the radiograph, a single experienced examiner measured joint space width (JSW) to assess degeneration, Sharp angle, lateral center edge (CE) angle, acetabular head index (AHI), and acetabular roof obliquity (ARO) to assess morphologic abnormalities. These measurements had high inter- and intrarater reliability[28,29], and are commonly used to diagnose dysplasia and hip OA[29]. Images were reviewed and measured on Centricity Enterprise Web, version 3.0 (GE Health care, Buckinghamshire, England). The JSW was measured at three locations, lateral margin of the subchondral sclerotic line, apical transection of the weight-bearing surface by a vertical line through the center of femoral head, and medial margin of the weight-bearing surface bordering on the fovea, in 0.1 mm increments from an image magnified 4 times (Fig. 1). If the minimum JSW was found aside from the 3 locations in the weight-bearing area, JSW of the narrowest point was also recorded as a fourth measurement. According to previous research[4], minimum JSW was defined as the smallest of these 3 or 4 measurements. The intrarater reliability [intraclass correlation (ICC) 1,1] of each radiographic measurement for 20 randomly selected radiographs was 0.95 to 0.99.

To assess the change in JSW, films at baseline and approximately 12 months later were paired by patients but blinded as to patient and sequence to the reader to avoid bias, as recommended[29]. All radiographic measurements were performed by the same examiner. Radiographic progression of hip OA has been defined as a reduction of more than 0.5 mm in JSW based on minimum detectable change (MDC) of the JSW[30,31]. Although the MDC_{95} (MDC at 95% confidence level) of the JSW in the current study was 0.39 mm by using the formula (MDC_{95} = standard error of measurement × √2 × 1.96), we defined reduction of more than 0.5mm/year in JSW at any of the 3 or 4 locations as hip OA progression.

(Fig. 1)

Pain and functional assessment

The average hip pain during daily life in the last 3 months was assessed on a 100-mm visual analog scale (0 = no pain and 100 = the worst imaginable pain). The Harris hip score was recorded to overview the functional status of the patient. Pain and functional assessment were conducted on the day of gait analysis.

Gait analysis

Gait-related variables were recorded using an 8-camera Vicon motion system (Vicon Nexus; Vicon Motion Systems Ltd. Oxford, England), at a sampling rate of 200 Hz with a fourth-order

Butterworth low-pass filter with a 6-Hz cut-off, and using force plates embedded flush with the floor (Kistler Japan Co., Ltd. Tokyo, Japan), at a sampling rate of 1,000 Hz with a low-pass filter (20 Hz). Patients were clothed in close-fitting shorts and T-shirts, and were asked to walk at a self-selected speed without assistive devices. To closely match usual daily walking, patients were given several practice trials before recording. The start position was adjusted so that participants could step on the force plate naturally. At least 3 successful trials for each patient were recorded for analysis.

Reflective markers were placed by a single experienced examiner. A total of 20 markers were placed bilaterally on the anterior superior iliac spine, posterior superior iliac spine, superior aspect of the greater trochanter, lateral femoral condyle, medial femoral condyle, lateral malleolus, medial malleolus, heel, fifth metatarsal head, and first metatarsal head. The pelvic segment contained 4 markers placed at the bilateral anterior superior iliac spine and posterior superior iliac spine. The thigh segment had 3 markers placed at the superior aspect of the greater trochanter and the medial and lateral femoral condyles. The shank segment had 4 markers placed at the medial and lateral femoral condyles and the medial and lateral malleoli.

We calculated 3-dimensional external joint moments of the hip using BodyBuilder software (Vicon Motion Systems Ltd. Oxford, England). The joint center of the hip was determined by first calculating a vector linking both greater trochanter markers. The joint center was then determined at a point interpolated at a distance of 18% of the vector norm from each reflective marker of the superior aspect of the greater trochanter along the vector[32]. The joint moment was calculated using a link segment model in which segments were connected together at nodal points. To compute the joint moment, coordinate data were added to the ground reaction force data, in which the position of the center of mass, weight portion, and moment of inertia of each segment were used as parameters. The peak external hip joint moment and hip joint moment impulse (area under the moment-time curve), were calculated for stance phase in each of the three planes (Fig. 2). Although the normalized value of the joint moment during gait is useful for group comparison, it can distract attention from the actual load on the joint[33]. Therefore, in the context of the purpose of evaluating the association between mechanical load during gait and hip OA progression, non-normalized values were used in moment peak and impulse according to a previous study[19]. Mean values of gait-related variables from 3 trials were calculated and used for analysis.

(Fig. 2)

Daily cumulative hip moment

A pedometer (EX-500, Yamasa Tokei Co. Ltd., Tokyo, Japan) with validated accuracy was given to all patients after being instructed in its use on the day of gait analysis[34,35]. We confirmed that the pedometers we used had good accuracy (±2.8%) when worn inside the pockets of the pants. Patients were asked to wear the pedometer from the time of awaking until the time of sleeping, both indoors and outdoors. The number of steps was recorded for 7 consecutive typical days within a month from the day of gait analysis. The duration of extraordinary events such as illness or traveling were excluded. We received the record of the number of steps via mail. Three to 5 days are believed to be required to reliably assess habitual physical activity[36]. However, we recorded steps throughout the entire week in consideration of differences between individuals regarding the balance of work days and non-work days within a week[37.] Daily cumulative hip moment was calculated as a product of the non-normalized hip moment impulse in each of the three planes and the mean number of steps/day for the affected limb (number of steps/day divided by 2)[20].

Statistical analysis

SPSS version 19.0 (IBM Japan Ltd., Tokyo, Japan) was used for statistical analysis. Normality of data was assessed using Shapiro-Wilk test. To test the hypothesis, univariable and multivariable logistic regression analyses with likelihood ratio tests were used to identify predictors of hip OA progression. The dependent variable was radiographic progression of hip OA (yes/no). Univariable logistic regression was performed to estimate each odds ratio (OR) and accompanying 95% confidence interval (CI). Multivariable logistic regression was performed to assess the association between load-related parameters during gait (i.e., peak hip moment, hip moment impulse, and daily cumulative hip moment) and radiographic progression of hip OA. Furthermore, as age, body weight, and minimum JSW at baseline can be potential confounders[2,20,38,39], those 3 variables were included in the multivariable model. Variables correlated at absolute coefficients > 0.7 were defined as multicollinearity[40]. A *P* value < 0.05 was considered statistical significant.

RESULTS

Baseline characteristics of patients are presented in Table I. Of the 50 patients, 21 (42.0%) were classified into the progression group. Change in JSW in the progression group was 1.3 ± 0.8 mm.

In the univariable logistic regression analysis (Table II), higher daily cumulative hip moment in the frontal plane at baseline was statistically significantly associated with progression of hip OA (crude OR [95% CI], 1.23 [1.01 to 1.49]; *P* = 0.038; Fig 3). Minimum JSW (crude OR, 0.68 [0.45 to 1.03]; *P* = 0.066) and steps/day (crude OR, 1.26 [0.99 to 1.61]; *P* = 0.062) were also potential predictors of hip OA progression.

In the multivariable analysis, higher daily cumulative hip moment in the frontal plane was statistically significantly associated with radiographic hip OA progression even after adjustment for age, body weight, and minimum JSW (adjusted OR, 1.34 [1.06 to 1.70]; *P* = 0.013; Table II). In addition, higher daily cumulative hip moment in the sagittal plane was also approaching statistical significance in its association with progression of hip OA (adjusted OR, 1.80 [0.99 to 3.26], *P* = 0.052; Table II). No statistically significant association was found between the peak and impulse of the hip moment and hip OA progression.

There was no multicollinearity between variables. No outlier defined as its residual outside 3 standard deviations was found. Although only 21 patients were included in the progression group, even the multivariable model (i.e., 4 independent variables) fulfilled the rule of a minimum of 5 events per variable[41].

(Table I)
(Table II)
(Fig. 3)

DISCUSSION

The most important finding of this study was that higher daily cumulative hip moment at baseline, particularly in the frontal plane, was a statistically significant independent predictor of hip OA progression. The finding supports our hypothesis, and to our knowledge, this study is the first to reveal an association between mechanical load during gait and radiographic progression of hip OA. The ratio of the patients in progression group (42.0%) was nearly the same as the ratio (34.5%) reported in a previous study although the study defined reduction of more than 0.6 mm/year in JSW as progression[42].

We included peak moment, moment impulse, and daily cumulative hip moment in load-related parameters during gait, since each variable can estimate hip joint load during gait from different aspects. Daily cumulative hip moment, rather than peak moment and moment impulse, was found as a predictor of hip OA progression. This indicates that the physical activity during a day as well as product of magnitude and duration of loading during a gait cycle must be considered for hip loading. The mean value of steps/day in the progression group (i.e., 7,411 ± 2,869 steps/day) was slightly higher than the age- and gender-specific standard value of steps/day in the same country (i.e., 7,373 ± 3,807 steps/day)[43]. Although it is not really known what type of stress causes cartilage damage provoking joint degeneration, repetitive loading even at the same level as that during level walking kill articular cartilage chondrocytes[44]. Repetitive loading can cause microdamage to accumulate; consequently, chondrocyte apoptosis can be induced, much like fatigue failure in engineering materials. Patients with more steps/day may accelerate the progression of hip OA by increased hip loading associated with excessive physical activity. Lifestyle changes through pacing of physical activity would be needed for such patients as it has been regarded as one of the key elements of non-pharmacological core management of OA[45].

In the 3-dimensional daily cumulative hip moments, that in the frontal plane was found as a statistically significant predictor of hip OA progression, and that in the sagittal plane was also a potential predictor of hip OA progression. In the hip moment impulses that compose cumulative hip moment, that in the frontal plane was largest (66.7% of the total); subsequently, that in the sagittal plane was large (25.7% of the total). Furthermore, change in hip contact force can be predicted by the change in hip moments in the frontal and sagittal planes. The first peak of the hip contact force during gait can be predicted well even by only the hip adduction moment, and combining the hip adduction and flexion moments increased coefficients of determination at the second peak hip contact force[17]. Therefore, it seems reasonable that daily cumulative hip moment, particularly in the frontal plane, was the important factor among the load-related parameters during gait related to hip OA progression. While body weight can directly affect joint moment during gait, daily cumulative hip moment in the frontal plane remained in the multivariable logistic model even after adjustment for body weight. This suggests the importance of change in gait pattern that increases the hip moment impulse compared with increases in joint loading due to overweight. Daily cumulative hip moment in the frontal plane is modifiable by gait modification (e.g., wide-based gait[17] and lateral trunk lean[46]), which can reduce hip adduction moment, and/or avoid excessive physical activity. Future studies should include a daily cumulative load modifying interventional trial to assess the causal relationship between joint load and hip OA progression more closely.

In the previous cross-sectional study[20], higher daily cumulative hip moment was associated with wider minimum JSW. However, in this cohort study, daily cumulative hip moment was higher and minimum JSW was narrower in the progression group than in the no-progression group. These findings seem contradictory; however, it would attribute to differences in dependent variables in the statistical analysis, not contradict. Daily cumulative hip moment was associated with hip OA progression even after adjustment for minimum JSW, which was also a potential predictor. It can be interpreted that each of the higher daily cumulative hip moment and narrower minimum JSW was an independent predictor when the hip OA progression was a dependent variable. The risk of progression of hip OA may be particularly high in the patients with both higher daily cumulative hip moment and narrower minimum JSW.

The finding that minimum JSW at baseline was a potential predictor of hip OA progression is consistent with those of previous studies, where the narrower the JSW at baseline, the faster the progression of hip OA[3] and the higher the need for THA[2]. This association can be explained by the finding that subchondral sclerosis associated with JSW narrowing and cartilage degeneration results in increased cartilage stress and pressure[47]. Patients with less JSW at baseline would potentially have tissue alterations which would hasten hip OA progression, and hip OA progression might have already begun in those patients at baseline in this study.

Several limitations to this study should be noted. Because the daily cumulative hip moment calculated in this study only reflects loading during steady waking, loading during other movement such as lifting, standing, and stair climbing may have been underestimated. However, it is difficult technically to measure the magnitude and duration of joint loading in daily life. Daily cumulative hip moment can be estimated by using both 3-dimensional gait analysis systems and pedometers; thus, it is difficult to measure the daily cumulative hip moment easily in clinical settings. More time- and cost-effective sensors that can measure cumulative joint load need to be developed in the future. The follow-up duration of 12 months was minimal. Although the yearly mean narrowing of the hip JSW has been reported as a risk factor for hastening of THA[48], a longer follow-up would be needed to establish the relationship between hip joint loading and degenerative change in articular cartilage. Furthermore, the change in the daily cumulative hip moment in 12 months was not measured; thus, which change in hip loading during gait affects radiographic change in hip joint is not yet known. Patients with hip JSW of < 0.5 mm were excluded from this study. The findings of this study could not be generalized to the relationship between gait biomechanics and hip OA progression in patients with end-stage OA. In addition, as this study included patients with secondary hip OA to reduce the heterogeneity of the study population, different predictors for hip

OA progression will be found in patients with primary hip OA, although primary hip OA is rare[7]. Nevertheless, the secondary hip OA group may show heterogeneity in our study. Identification of the predictor of hip OA progression might be necessary with respect to each subgroup of secondary hip OA. Finally, we used a logistic regression analysis to estimate the adjusted OR because relative risk could not be calculated in some of the independent variables. However, the OR underestimates or overestimates the relative risk when the event being modeled is not rare (>10%)[49].

In conclusion, this study revealed that the higher daily cumulative hip moment at baseline, particularly in the frontal plane, was associated with the radiographic progression of hip OA defined by a > 0.5-mm cartilage thickness loss in 12 months. Our findings may help identify patients with a higher risk of hip OA progression and clarify the target of intervention to slow hip OA progression.

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Author Contributions

HT: concept and design, obtaining of funding, analysis and interpretation of the data, drafting of the article, and final approval of the article. HT was the main investigator of this study, and performed all of the measurements.

YK: acquisition of data, analysis and interpretation of data, critical revision of the article for important intellectual content, and final approval of the article.

HA: provision of study patients, analysis and interpretation of data, critical revision of the article for important intellectual content, and final approval of the article.

KG: provision of study patients, analysis and interpretation of data, critical revision of the article for important intellectual content, and final approval of the article.

KS: provision of study patients, analysis and interpretation of data, critical revision of the article for important intellectual content, and final approval of the article.

YK: provision of study patients, analysis and interpretation of data, critical revision of the article for important intellectual content, and final approval of the article.

NI: concept and design, obtaining of funding, analysis and interpretation of data, critical revision of the article for important intellectual content, and final approval of the article.

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Competing interest

There are no conflicts of interest to declare with regard to this study.

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Table I. Baseline characteristics of study participants

(Footnotes for Table 1)

Values are reported as mean ± standard deviation. VAS = visual analogue scale; JSW = joint space width; CE angle = center edge angle; AHI = acetabular head index; ARO = acetabular roof obliquity.

	All patients (n = 50)	No progression (n = 29)	Progression (n = 21)
Age, years	47.4 ± 10.7	46.6 ± 10.2	48.6 ± 11.6
Weight, kg	55.2 ± 10.2	54.2 ± 9.8	56.5 ± 10.9
Height, cm	156.9 ± 5.6	157.5 ± 6.8	156.1 ± 3.5
Minimum JSW, mm	3.3 ± 1.4	3.7 ± 1.4	2.9 ± 1.4
Pain (VAS), mm	42.0 ± 27.5	37.7 ± 1.4	47.9 ± 26.4
Harris hip score (total 100 points)	86.9 ± 9.9	87.9 ± 8.7	85.6 ± 11.4
Morphology parameters			
Sharp angle, degrees	45.0 ± 6.5	45.6 ± 7.4	44.1 ± 4.8
CE angle, degrees	23.4 ± 11.5	22.0 ± 11.1	25.5 ± 12.1
AHI, degrees	73.8 ± 11.0	72.8 ± 10.7	75.2 ± 11.6
ARO, degrees	22.4 ± 7.9	22.8 ± 8.6	21.8 ± 7.0
Gait-related parameters			
Gait speed, meters/seconds	1.1 ± 0.2	1.2 ± 0.2	1.1 ± 0.1
Steps/day	6,596 ± 2,552	6,005 ± 2,157	7,411 ± 2,869
Load-related parameters during gait			
Peak external hip moment, Nm			
Hip flexion moment	39.1 ± 9.8	39.5 ± 8.9	38.6 ± 11.2
Hip extension moment	25.5 ± 8.7	25.3 ± 7.3	25.7 ± 10.5
Hip adduction moment	57.9 ± 16.0	56.9 ± 16.2	59.3 ± 16.0
Hip internal rotation moment	9.0 ± 3.9	9.5 ± 3.5	8.3 ± 4.3
Hip external rotation moment	6.2 ± 2.5	6.1 ± 2.4	6.4 ± 2.6
Hip moment impulse, Nm•seconds			
Sagittal plane	8.4 ± 2.7	8.4 ± 2.1	8.5 ± 3.5
Frontal plane	22.7 ± 7.4	21.4 ± 7.3	24.5 ± 7.2
Transversal plane	2.5 ± 0.8	2.5 ± 0.7	2.5 ± 1.0
Cumulative hip joint moment, kNm•seconds			
Sagittal plane	27.6 ± 13.4	25.2 ± 10.3	30.8 ± 16.6
Frontal plane	74.6 ± 41.4	63.0 ± 29.4	90.6 ± 50.2
Transversal plane	8.4 ± 5.4	7.6 ± 3.7	9.5 ± 7.0

Table II. Univariable and multivariable logistic regression predicting the progression of hip osteoarthritis (n = 50)

(Footnotes for Table 2)

OR = odds ratio; 95% CI = 95% confidence interval. VAS = visual analogue scale; JSW = joint space width; CE angle = center edge angle; AHI = acetabular head index; ARO = acetabular roof obliquity.

* Unit is 1,000 steps/day. † Adjusted for age, body weight, and minimum JSW.

	Crude OR (95% CI)	*P* value	Adjusted OR† (95% CI)	*P* value
Age, years	1.02 (0.97 to 1.08)	0.499	–	–
Weight, kg	1.02 (0.97 to 1.08)	0.426	–	–
Minimum JSW, mm	0.68 (0.45 to 1.03)	0.066	–	–
Pain (VAS), mm	1.01 (0.99 to 1.04)	0.198	–	–
Morphology parameters				
Sharp angle, degrees	0.96 (0.88 to 1.06)	0.407	–	–
CE angle, degrees	1.03 (0.98 to 1.08)	0.286	–	–
AHI, degrees	1.02 (0.97 to 1.08)	0.447	–	–
ARO, degrees	0.98 (0.92 to 1.06)	0.654	–	–
Gait-related variables				
Steps/day*	1.26 (0.99 to 1.61)	0.062	–	–
Gait speed, meters/seconds	0.13 (0.00 to 4.73)	0.268	–	–
Load-related parameters during gait				
Peak external hip moment, Nm				
Hip flexion moment	0.99 (0.94 to 1.05)	0.758	0.99 (0.93 to 1.05)	0.640
Hip extension moment	1.01 (0.94 to 1.07)	0.877	0.99 (0.92 to 1.06)	0.701
Hip adduction moment	1.01 (0.97 to 1.05)	0.597	0.99 (0.94 to 1.05)	0.760
Hip internal rotation moment	0.92 (0.78 to 1.07)	0.278	0.88 (0.73 to 1.05)	0.160
Hip external rotation moment	1.05 (0.84 to 1.33)	0.670	1.03 (0.80 to 1.34)	0.799
Hip moment impulse, Nm•seconds				
Sagittal plane	1.01 (0.82 to 1.24)	0.950	1.00 (0.80 to 1.26)	0.971
Frontal plane	1.06 (0.98 to 1.15)	0.155	1.09 (0.96 to 1.24)	0.190
Transversal plane	0.90 (0.45 to 1.80)	0.774	0.83 (0.36 to 1.91)	0.663
Cumulative hip joint moment, 10kNm•seconds				
Sagittal plane	1.39 (0.88 to 2.21)	0.159	1.80 (0.99 to 3.26)	0.052
Frontal plane	1.23 (1.01 to 1.49)	0.038	1.34 (1.06 to 1.70)	0.013
Transversal plane	2.01 (0.61 to 6.68)	0.253	2.93 (0.71 to 12.11)	0.253

Figure legends

Fig 1. The three measurement locations of the joint space width (JSW) of the hip joint. If the minimum JSW was found aside from the three locations, it was recorded as a fourth measurement.

Fig. 2. A typical example of the hip joint moment curve in sagittal (thin black line), frontal (thick black line), and transversal (grey line) plane during stance phase of walking. Positive values indicate external hip flexion, adduction, and external rotation moment, respectively.

Fig. 3. Distribution of daily cumulative hip joint moment in the sagittal (A), frontal (B), and transversal plane (C) in each of no progression group (white) and progression group (grey). Boxplots with upper and lower bars showing maximum and minimum values. Upper, middle, and lower lines in the box indicate 75th, 50th (median), and 25th centiles, respectively. The cross mark in the box indicates the mean value.

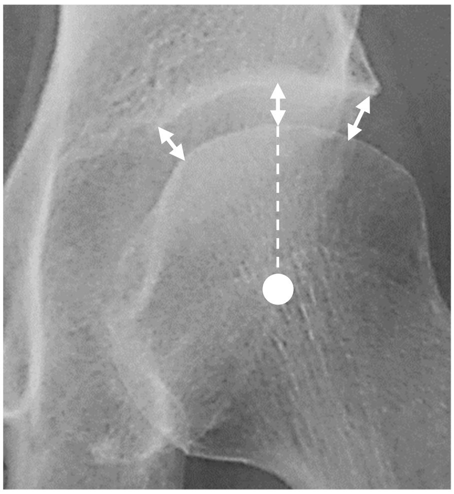

Fig. 1.

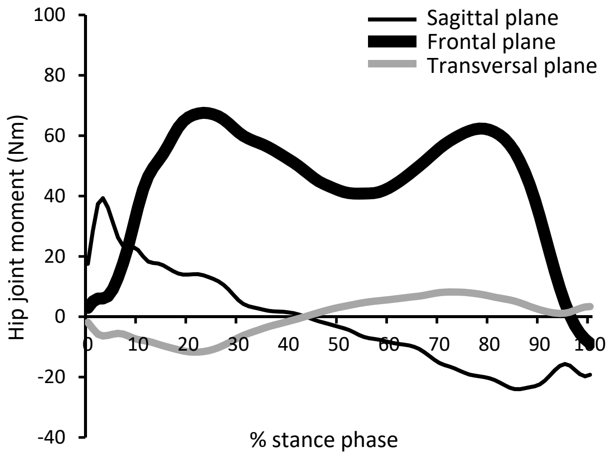
Sagittal plane
Frontal plane
Transversal plane
Hip joint moment (Nm)
100
80
60
40
20
0
-20
-40
0
10
20
30
40
50
60
70
80
90
100
% stance phase

Fig. 2.

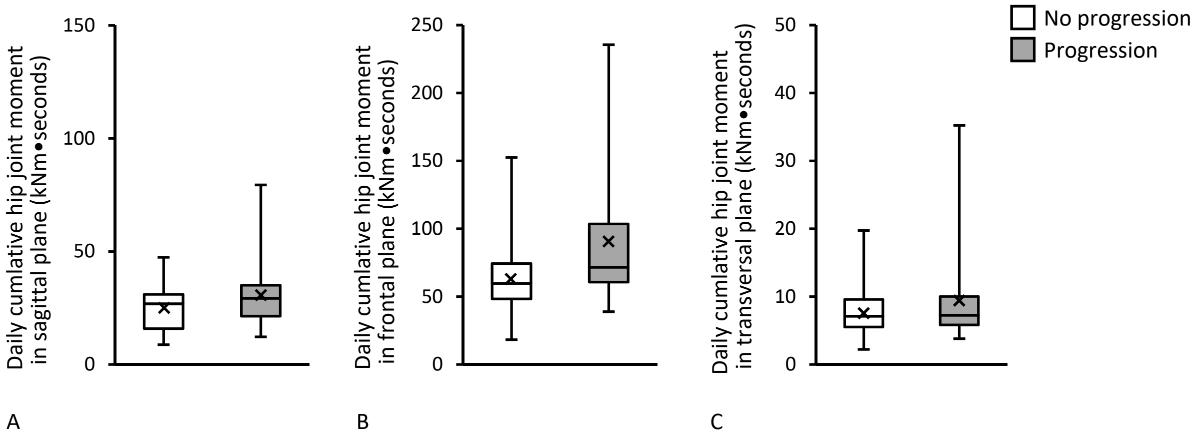
Daily cumlative hip joint moment in sagittal plane (kNm•seconds)
150
100
50
0
A
Daily cumlative hip joint moment in frontal plane (kNm•seconds)
250
200
150
100
50
0
B
Daily cumlative hip joint moment in transversal plane (kNm•seconds)
50
40
30
20
10
0
C
No progression
Progression

Fig. 3.